IPM Gain Calibration Status and Plan for Run13

R. Connolly, M. Minty, T. Summers, S. Tepikian

A RHIC IPM produces an image of the beam profile by collecting electrons removed from background gas by beam ionization, amplifying this electron signal with a microchannel plate (MCP), and measuring the charge collected on 64 collector channels.

There are three sources of profile measurement error,

Accuracy of electron transport from the beam to the MCP

This limits the resolution of an IPM to about 0.4mm, i.e., a δ-function beam would produce an image with a width of $\sigma \approx 0.4$mm. This limit is set by the strength and accuracy of the guiding magnetic field.

Variation of electron flux amplification by the MCP caused by MCP aging

This becomes an issue when the MCP ages over several runs. Symptoms of MCP aging are errors which vary smoothly over the measurement aperture and vary with beam size.

Gain and offset variations among the 64 amplifier/digitizer channels

This causes random variations in measured widths as the beam steering changes in the IPM.

This talk addresses the MCP and amplifier gains.

The IPMs in RHIC have displayed three emittance measurement anomalies:

The horizontal and vertical IPMs have reported different emittances.

This is being addressed by making β function measurements at the IPMs. These were started in Run 12 and will be continued in Run 13.

The emittance has decreased on the acceleration ramp.

This is an artifact caused by excessive aging of the MCPs. The first part of this talk discusses this.

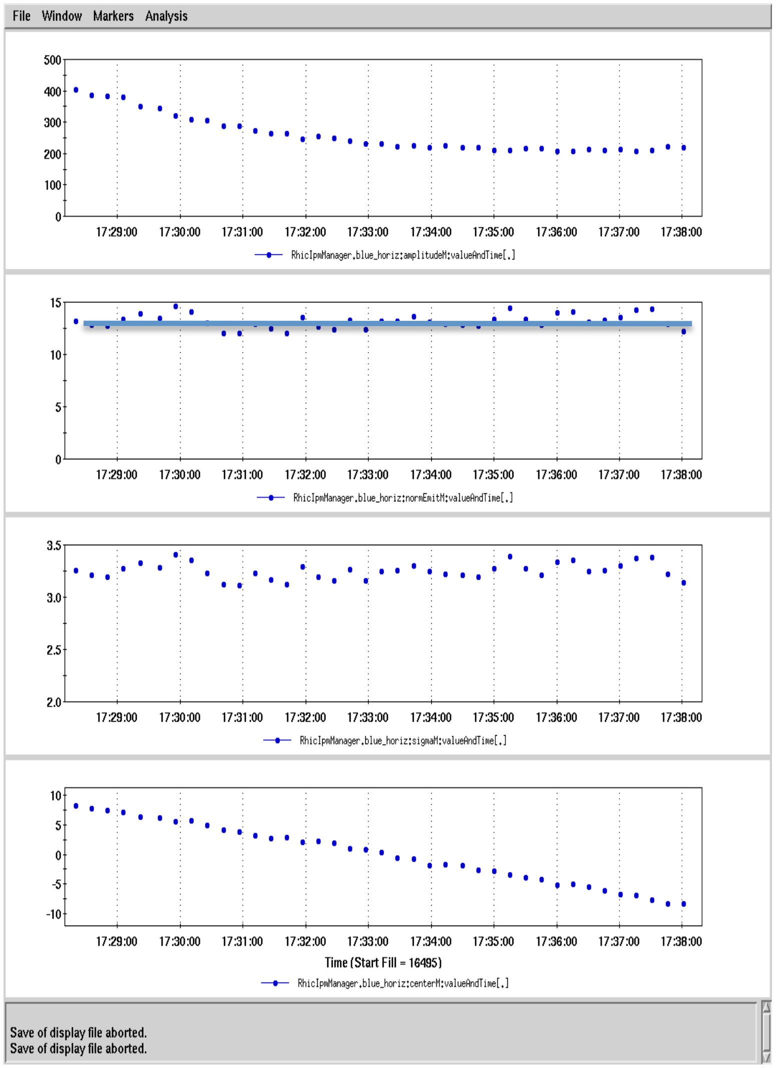
The emittance changes with beam position in the detector.

A contributing factor here is gain and offset fluxuations among the 64 data channels. We did calibration measurements manually in Run 11 to address these issues.

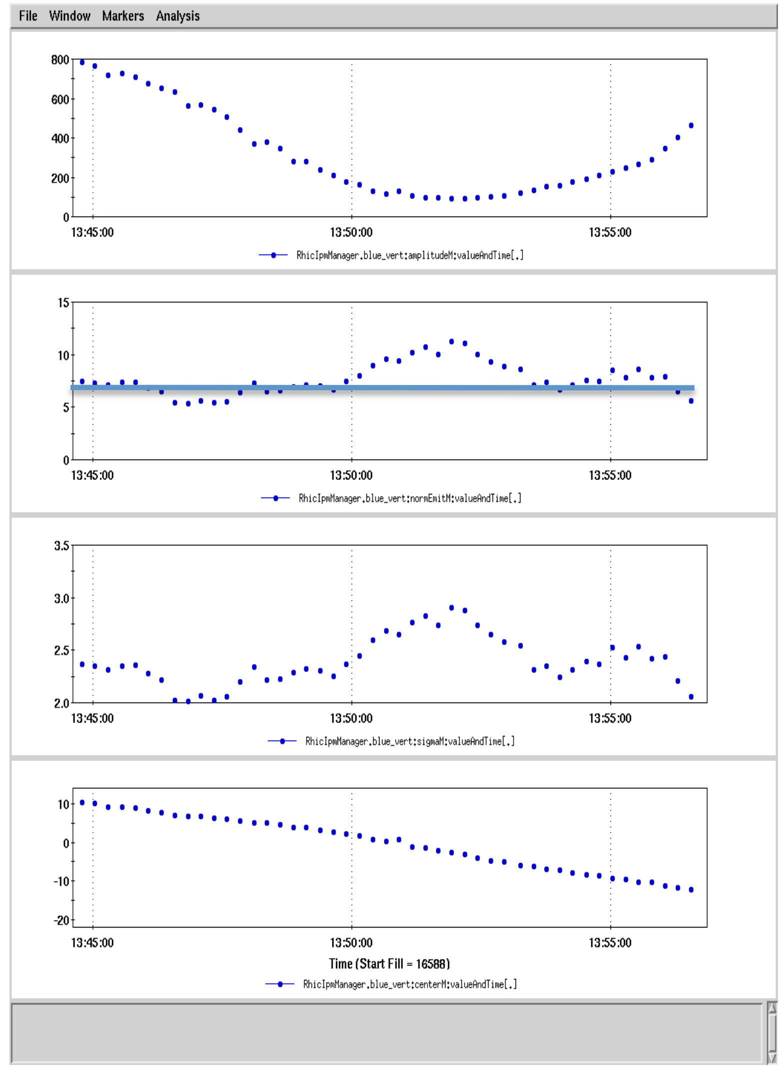
In Run 12 we developed a TAPE sequence for taking sets of profile scans for each RHIC IPM. This program moves the beam across the selected IPM measurement aperture in equal-sized steps. At each position the IPMs are triggered.

Examples of two Blue-ring IPM calibration scans from March,

Blue Horizontal, 3rd run for MCP



Blue Vertical, 8th run



Amplitude

Emittance

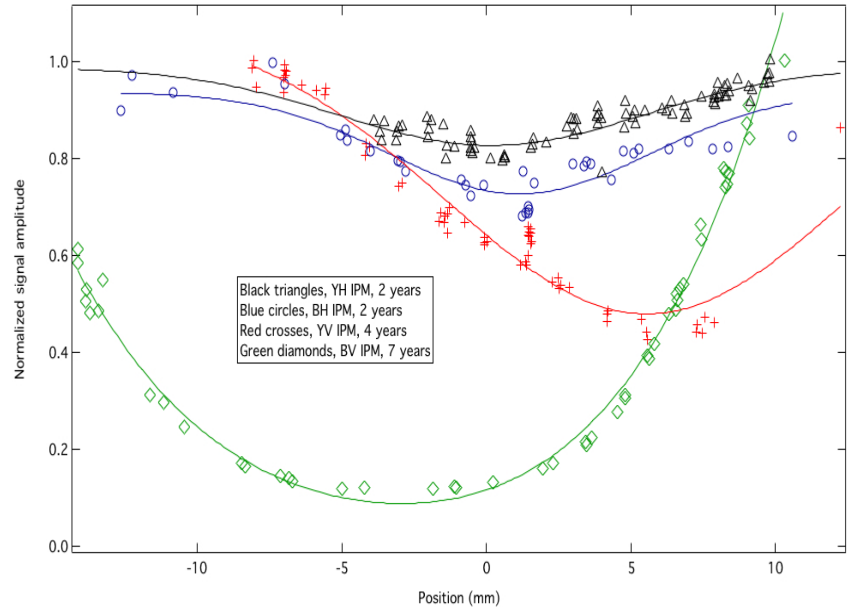
Sigma

Beam center

The BV MCP is far more depleted than BH. As the beam is scanned across the aperture, the BV IPM shows a systematic increase in the measured emittance across the most depleted area of the MCP.

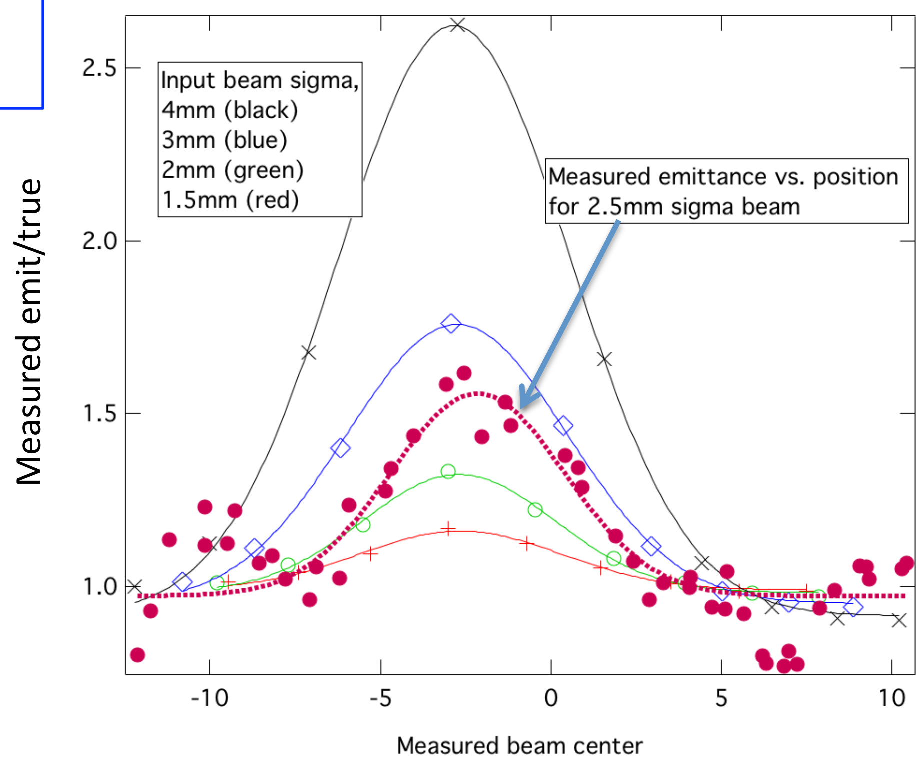
MCP gain depletion effects

As we move the beam over the measurement aperture of each IPM <u>with gain feedback off</u> the amplitude of the profile changes with position of the beam. This plot shows normalized gain patterns for the four IPMs.



To study the effect of MCP aging on the IPM measurements I applied these gain patterns to simulated Gaussian beams of σ = 1.5, 2, 3 and 4 mm and fit Gaussians to the results. The results are plotted for the Blue vertical.

Also plotted is the measured emittance using a beam of σ=2.5mm from the last slide.



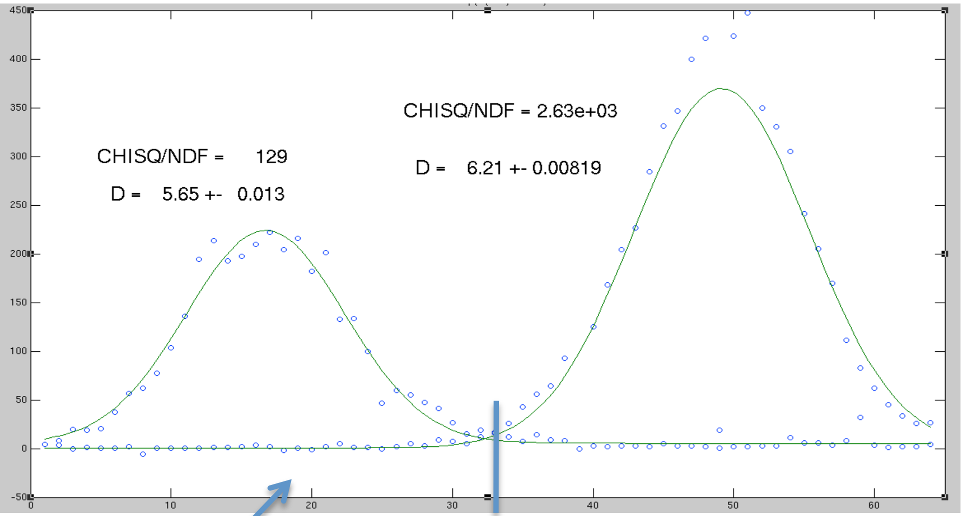
These measurements and simulations show that in the nominal beam location an MCP loses about 10% of its initial gain each run. This gain loss causes an emittance measurement variation with beam position and with beam size.

This effect contributes to the observed decrease of emittance up the acceleration ramp in the most depleted MCPs. It was not apparent in the third beam runs of the horizontal IPMs.

Using scan data to find gain and offset corrections

The MCP amplifies the flux of electrons from gas ionization while preserving its spatial distribution. The MCP is mounted on a circuit board with 64 collector anodes. Each anode has its own amplifier and ADC. We want to use the scan data to remove errors caused by gain and offset variations among the data channels.

To analyze the data we assume only that the beam profile is Gaussian.

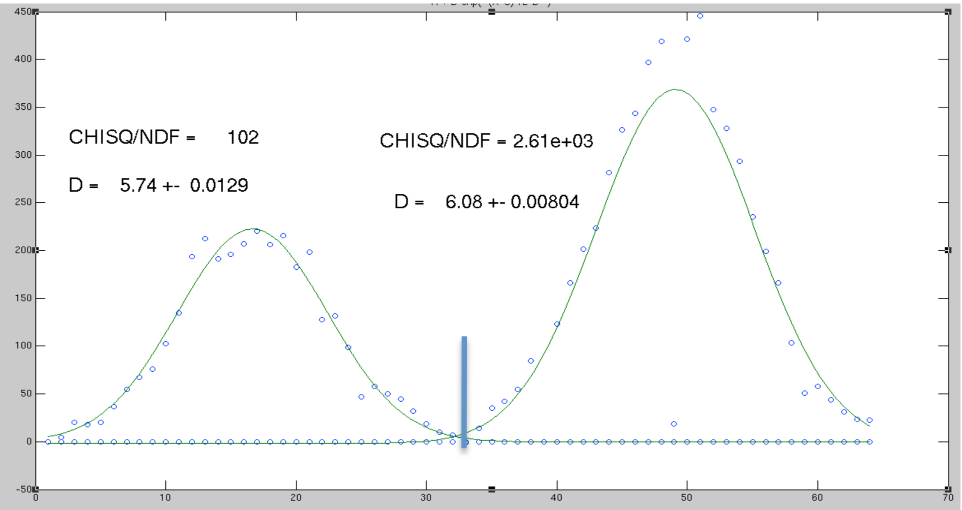


Raw data

DC offsets

We identify the profiles at the two ends of the scans. The offset values for the low channels are taken from the far right profile, and the high channels from the left profile.

Offsets subtracted



Here are profiles 1 and 41 from the BH scan set with fitted Gaussians. The χ^2 fits and beam sigma of the fits are shown.

Identify and correct bad channels

In each IPM there are a few channels that are extreme outliers, usually from non-operating amplifiers, (channel 49, arrow).

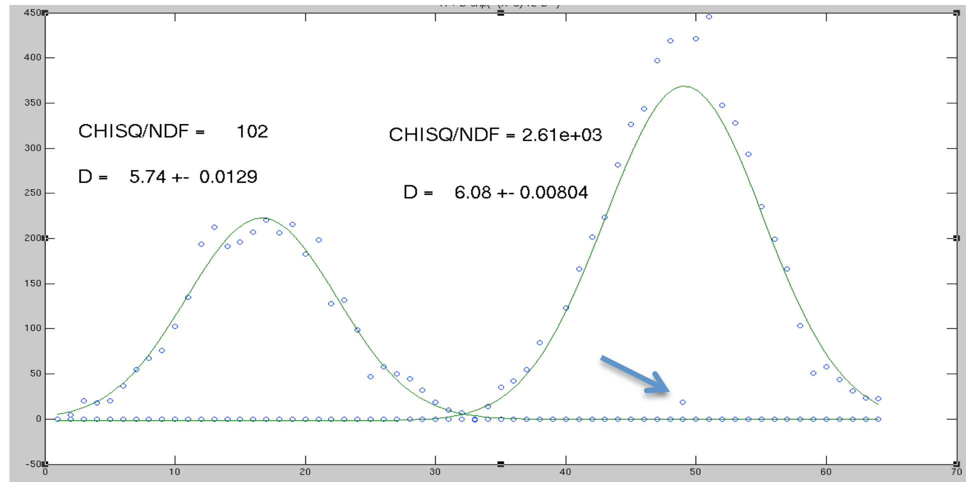
A scan consists of *Ndatasets* profiles across the IPM, (41 in this example). We fit a Gaussian to each profile, calculate the value of the fit at each channel, and for each channel subtract the measured value from the fitted value. These errors are all squared.

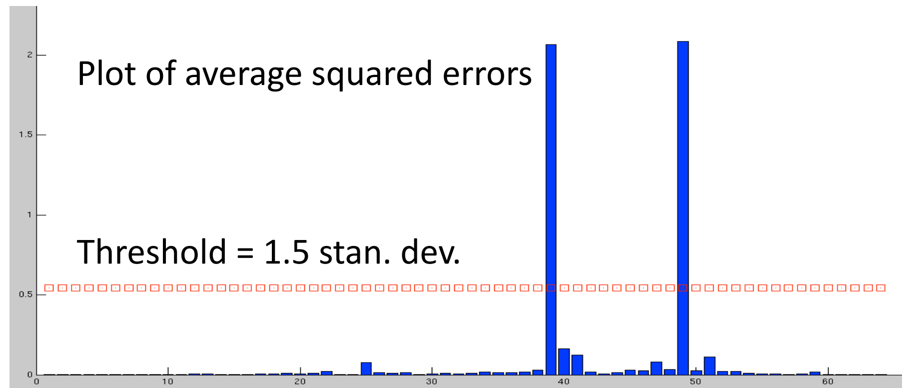
This process generates *Ndatasets* of 64 squared errors.

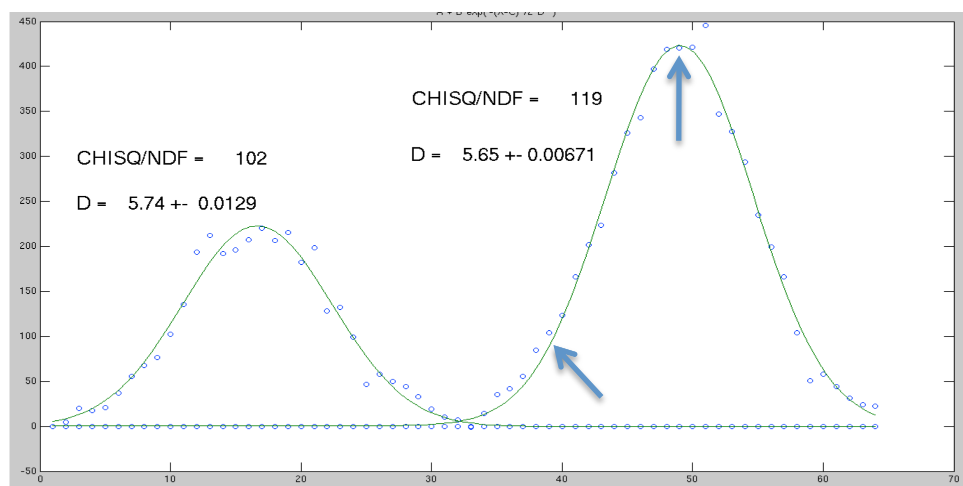
For each channel we find the average of the errors giving a single vector of 64 values.

We find the standard deviation of this list and define the bad channels as ones with the average squared error > 1.5 standard deviations.

Each bad measurement value is replaced with the average of the two measured values on either side of the bad channel. (Arrows bottom plot)







Generating gain corrections

We now have a matrix, **M**, of 64 x *Ndatasets* measurement values which have offsets removed and bad channels repaired.

A Gaussian is fitted to each dataset and the values of the fit at each channel is calculated. This produces a matrix, **F**, of 64 x *Ndatasets* of fitted values.

We define a gain correction vector, **G**, of 64 values, all initialized to 1.

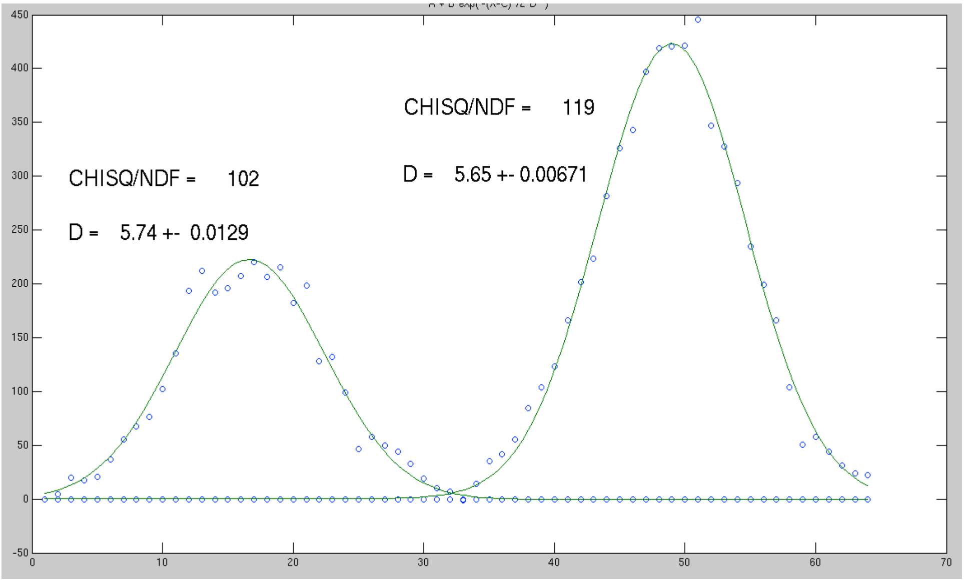
An error matrix, **E**, is generated by multiplying each column of **M** by **G** and subtracting the resulting matrix term-by-term from **F**.

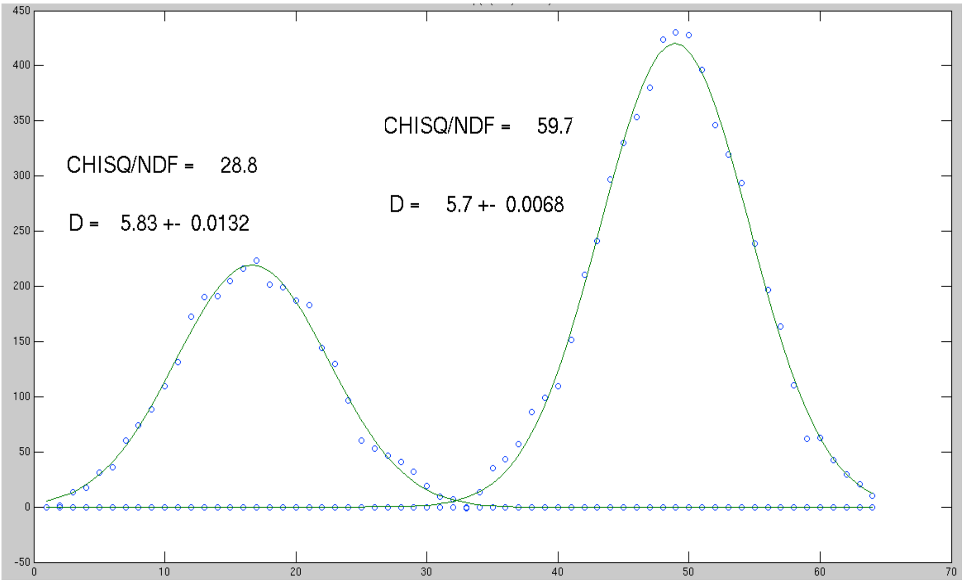
All terms in **E** are squared and all 64x*Ndatasets* squared errors are added, producing a single value ESQ.

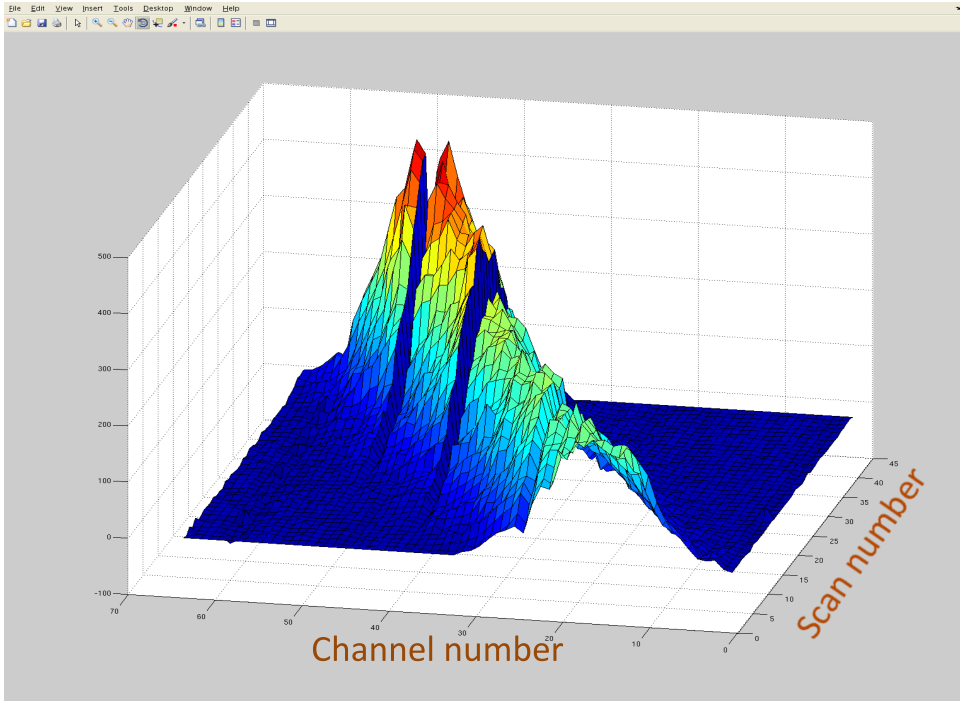
These operations are combined into a function whose inputs are the matrices **M** and **F** and the vector **G** and whose output is ESQ.

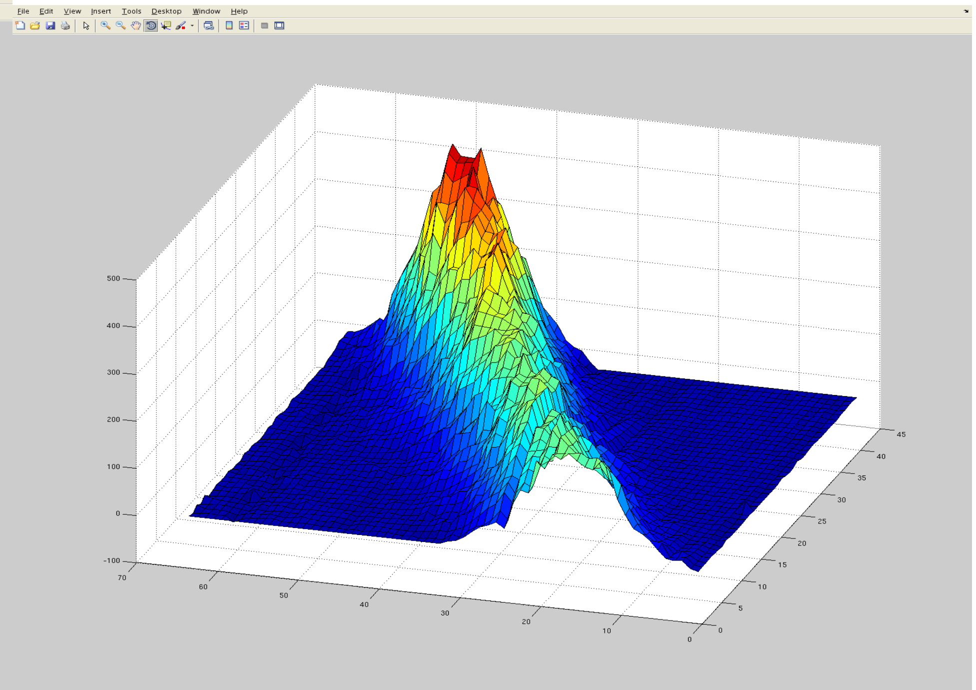
$$ESQ = f(\mathbf{M}, \mathbf{F}, \mathbf{G})$$

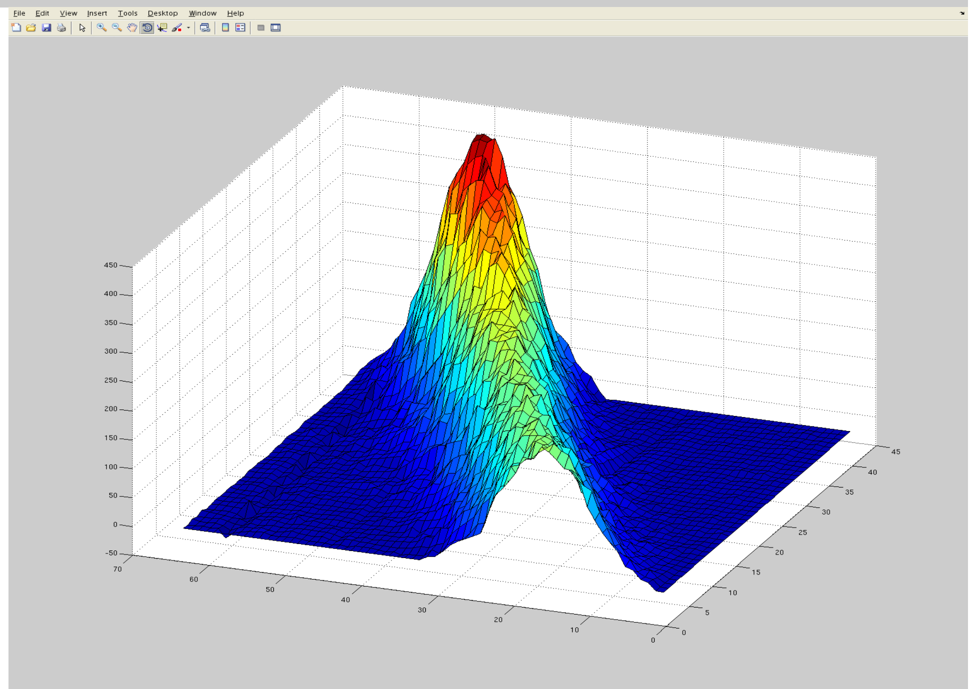
Finally we use a Matlab fitting routine 'fminsearch' to minimize ESQ by varying the 64 values of **G**.











Evolution of measurement matrix

Top is series of scans with only background subtraction. Channels 39 and 49 are clearly bad.

Top right is after the bad channels have been ‘repaired’.

Right is the top right matrix with the gain corrections applied.

Discussion

Measurements and simulations show that MCP gain depletion from aging produces a position-dependent beam size error. This error is negligible for the small RHIC beams at store and only appears after at least three beam runs.

In Run 12 a TAPE sequence was developed to step the beam across the measurement aperture of the IPMs to generate a series of profile measurements. MATLAB software was developed to find offsets and gain corrections for the 64 data channels from this data.

The gain correction algorithm assumes only that the beam is Gaussian.

The example shown here is for a 41 profile scan of the Blue Horizontal IPM. Results for this data set:

The beam sigmas for the two extreme profiles before and after the corrections are shown here. The raw data gives widths that differ by 10% but the corrected data show a difference of 2%.

sigma	Profile 1	Profile 41
Raw data	5.65 channels	6.21 chans
Corrected	5.83 chans	5.70 chans

Gaussian fits were done on all 41 profiles with the raw data and the corrected data. The rms scatter in the measured profiles is reduced from 4.5% to 2.6%. This final value represents the inherent reproducibility of the measurement process.

Raw data	Corrected data
$\sigma = 6.10 \pm 0.28$	$\sigma = 6.05 \pm 0.16$

Run 13

We will continue to improve the β-function measurements.

We will monitor the MCP gain depletion, however this should not be a problem in Run13 since both vertical IPMs have been replaced during this shutdown.

The MCPs in the horizontal IPMs should be fine for Run 13. We are prepared to replace these MCPs when the beamlines are vented to install the new stochastic-cooling pickups.

We will do calibration measurements on the IPMs early in the run and implement the gain corrections.

We have updated the IPM data logging. On every measurement we log:

1. Raw data
2. Gain vector
3. Offset vector
4. List of channels that were excluded from the Gaussian fit.